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Koch, Cathérine Tahmee

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# Risky Adjustments or Adjustments to Risks: Decomposing Bank Leverage

Cathérine Tahmee Koch\*

March 6, 2014

## Abstract

By use of cointegration analysis, this paper splits bank leverage into a short- and long-run dimension. Regarding the long run, if banks' leverage ratios or related liability shares are stable over time, they form a cointegrating relationship. Thus, cointegration tests indicate whether banks' liability ratios were stable or subject to structural breaks during the financial crisis in 2007 and 2008. By endogenous identification of structural breaks, my analysis tracks the precise channels of banks' leverage adjustments. Findings on the long run suggest that banks cut their leverage twice. In June 2007 banks significantly reduced their foreign debt, while in April 2008 they withdrew from interbank borrowing. Regarding the short run, I study how banks adjust to the dynamics of risk proxies from distinct financial markets. Findings on the short run point out that banks' reactions to risks differ considerably across different types of financial markets.

JEL codes: C32, F65, G21

Keywords: banking crises; capital regulation; liability structure; cointegration

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\*University of Zurich, Department of Economics, Zuerichbergstrasse 14, CH-8032 Zurich, Switzerland. Email: catherine.koch@econ.uzh.ch. URL: <http://www.econ.uzh.ch/faculty/koch.html>.

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# 1 Introduction

The Lehman collapse of September 2008 marks the climax of a crisis that started to unnerve financial markets in 2007. A surging number of defaults troubled the sub-prime mortgage market in February 2007 and this trouble soon spread to other markets by interconnected financial intermediaries. In 2008, uncertainty paralyzed the interbank market and made several banks stumble. This financial market turmoil represents a fundamental change in bank funding conditions. My paper sheds light on the liability management of large commercial, globally operating German banks from a short- and long-run perspective against the background of key events during this financial crisis. Many large, possibly systemically relevant banks from other developed countries share these traits and business models. Thus, my paper contributes to a better understanding of global banks' leverage and liability management.

From a long-run perspective, if banks exhibited constant liability ratios – of for instance equity to the balance-sheet total – a decomposition of all liabilities and the balance-sheet total would form a cointegrating relationship. Hence, cointegration analysis can test whether banks target distinct liability ratios and it can identify structural breaks in leverage ratios or related liability shares during 2007 and 2008. The identification of these structural breaks proves to be useful for two reasons. First, my analysis endogenously locates these structural breaks and thereby points at key crisis events that have triggered major liability reallocations. Second, estimated interaction coefficients disclose the precise channels of leverage adjustments that banks invoke to handle ruptures in their funding conditions. I can hence track the channels of deleveraging by studying how banks reallocate various liabilities in response to fundamental ruptures during 2007 and 2008. I find that banks cut their leverage twice. In June 2007, banks significantly reduce their exposure to foreign markets while partly replacing foreign debt by domestic debt and bond finance. In April 2008, they withdraw from interbank borrowing while hardly tapping alternative funding.

From a short-run perspective, my analysis draws on vector error correction models to examine how banks respond to the dynamics of risk proxies from distinct markets of their activity.

It also sheds light on those liability components which correct for short-run deviations to restore the long-run targeted ratios. To proxy these financial market risks that trigger short-run deviations from long-run ratios, I resort to four different risk proxies: the *VIX* index reflects risks on equity markets, the *risk spread* sheds light on fixed income markets, the J.P. Morgan *FX-VXY* index refers to currency markets and the Credit Suisse First Boston's (*CSFB*) *Risk Appetite* index measures risk appetite across several markets. I find that banks respond differently to the risk dynamics in different markets and countries. Higher risks on equity markets encourage banks to raise their leverage, whereas banks seem to care less about currency markets. More risk appetite in general seems to deter banks from jumping on the bandwagon. Overall, interbank debt turns out to perform a key valve function while responding most to considered risk measures.

A tailored version of the workhorse banking model by Baltensperger and Milde (1987) helps me to form hypotheses about the optimal adjustment patterns in the long and short run. The empirical analysis of this paper exploits comprehensive supervisory balance-sheet data provided by the *Deutsche Bundesbank* on large commercial banks headquartered in Germany. Hence, the estimation sample draws on globally operating banks with a comprehensive business model that exposes these bank to all kinds of domestic and foreign shocks. Since many large commercial banks on the international stage share the characteristics of large commercial German banks, my findings are applicable to many banks possibly deemed systemically relevant which are headquartered in major developed countries.

The contribution of my paper is twofold. First, to the best of my knowledge, this is the first paper which applies cointegration analysis to split bank leverage into a short- and a long-run dimension. Hence, it is also the first paper to interpret structural breaks in cointegrating relationships as channels of leverage adjustment. Second, my identification of endogenous breaks and subsequent reallocation patterns contributes to a thorough understanding of how exactly banks respond to key crisis events and how they transmit shocks to different markets. I use detailed balance-sheet data, to examine the reallocation among liabilities and thus the liability channels to adjust leverage. My analysis informs the debate on government interventions

and contributes to an appropriate design of regulation on leverage and the overall liability structure.

This paper proceeds in several steps. A brief review of the relevant literature follows this outline. Section 3 describes the bank balance-sheet setup and offers the liability decomposition into four core sets which form the backbone of my empirical analysis. This section also derives the long-run cointegrated relationships. Turning to the empirical part, Section 4 presents the applied econometric tools and provides results on the long run, estimated endogenous structural breaks and the short run. Finally, Section 5 concludes.

## 2 Literature Review

My paper builds on two strands of the economic literature. The first strand relates balance-sheet dynamics and key issues of the banking business such as liquidity, leverage and lending to exogenous shocks. In a narrow sense, it elaborates on the so-called *bank-lending channel* stating that characteristics of bank balance sheets shape their response to monetary policy decisions (see for instance Bernanke and Blinder, 1988). The idea that heterogeneity among banks governs the effectiveness of monetary policy as exogenous shocks has sparked a sizable literature. My review presents only a selection. In a seminal paper, Kashyap and Stein (2000) argue that monetary policy exercises a stronger impact on those banks with less liquid balance sheets. Kishan and Opiela (2000) add that the smallest and least capitalized banks turn out to be as most responsive. Cetorelli and Goldberg (2009) broaden the scope. They find that international operations shield banks from domestic monetary policy as internal capital markets reinforce or weaken the propagation of shocks. With the global banking crisis of 2008 the focus has shifted. Now the literature explores how balance-sheet characteristics and key issues of the banking business shape the response to financial market shocks. Ivashina and Scharfstein (2010) find that after the Lehman collapse banks that had been more exposed to the short-term debt market and credit-line draw-downs reduced their lending more sharply than did their competitors. Puri et al. (2011) identify a significant reduction in the lending

of those savings banks that were linked to head institutions with a high exposure to the US sub-prime market. The twofold role of foreign banks in the financial crisis is explored by Cetorelli and Goldberg (2012). They show that global banks transmit shocks by relating the parent bank's funding needs to the balance-sheet contraction of foreign affiliates. Giannetti and Laeven (2012) put forward that the collapse of the syndicated loan market is traceable to banks re-balancing their portfolio in favor of domestic rather than foreign lending. The focus of this literature lies on banks' lending decisions and thus the asset side of the bank balance sheet. As distinct from these papers, my analysis deals with adjustment patterns on the liability side in response to shocks. It further disentangles leverage adjustments to identify distinct channels of liability allocations.

The second strand of the literature deals with the methodology applied in this paper. To distinguish long-run and short-run dimensions, I refer to the consumption-wealth literature. By interpreting a balance sheet as a budget constraint in present value form, I motivate the link between balance-sheet constraints and cointegration analysis. Campbell and Mankiw (1989) lay the cornerstone for this type of model and Lettau and Ludvigson (2001) link them to financial market developments. Hoffmann (2006) allows for trend breaks and splits the cointegrating relationship with all components into three relationships drawing on two variables. Several recent papers explore long-run economic relationships while searching for endogenous breaks. In this sense, Camarero et al. (2013) examine the link between net foreign asset positions and the current account, Beckmann et al. (2011) study exchange rates and their relationship to macroeconomic fundamentals while Haug et al. (2011) and Magonis and Tsopanakis (2013) look at interest rate parity conditions.

As distinct from that, my empirical approach identifies endogenous structural breaks in the long-run bank liability ratios. Cointegration analysis allows me to interpret structural breaks in terms of balance-sheet reallocations. Thereby, I can identify the liability channels that banks invoke to adjust their leverage in response to shocks. Indeed, Bai (1994, 1997), Kurozumi (2002) and Carrion-i Silvestre and Sansó (2006) provide the toolkit to identify endogenous breaks and to test for cointegration given structural breaks in the cointegrating vector. My

paper greatly benefits from these presented tools and applies them to balance-sheet ratios.

### 3 Deriving the Empirical Approach

#### 3.1 Decomposing Leverage

This section introduces the liability decomposition sets and relates them to the concept of leverage.<sup>1</sup> Let capital letters denote balance-sheet items as indicated by banks in levels and denominated in euro. The balance-sheet identity states that sources of *internal* and *external* finance sum up to the balance-sheet total (*TBS*). *EQUITY* corresponds to subscribed capital as a source of internal finance. The following items characterize sources of external finance (*EFIN*): *BONDS* capture issued securitized debt, *DEBT* features non-securitized debt, such as deposits and borrowed funds while *LOTHER* serve as a residual catchall item of other liabilities. To shed light on the (de-)leveraging process, my empirical analysis draws on four distinct decompositions of the liability side: set I, the baseline decomposes the balance-sheet total into *EQUITY*, *BONDS*, *DEBT* and *LOTHER*. Set II adds a distinction between *foreign* and *domestic debt*, set III splits debt into *short-term* and *long-term* debt, while set IV separates *bank* from *non-bank debt*.<sup>2</sup>

According to the balance-sheet identity, *EQUITY*, *BONDS*, *DEBT* and *OTHER LIABILITIES* add up to the balance-sheet total (*TBS* hereafter). Thus, leverage can be expressed by liability components as:

$$Leverage = TBS/(EQUITY) = TBS/(TBS-EFIN) = TBS/(TBS-DEBT-BONDS-LOTHER) \quad (1)$$

Hence, changes in leverage may ensue from non-offsetting changes in the components of set I to set IV.

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<sup>1</sup>An online appendix to this paper which provides complementary graphs and tables is available at <http://www.econ.uzh.ch/faculty/koch.html>. It sketches a stylized balance sheet with mutually exclusive items in bold print. The liability side of this balance sheet broadly imitates an official form (“HV12”) that the Bundesbank makes available for banks to report supervisory data.

<sup>2</sup>Table 1 gives the ultimate specifications in terms of potentially cointegrating relationships.

### 3.2 Econometric Traces of Changes in Leverage

The aim of this section is to derive possibly cointegrating relationships between various liability components and the balance-sheet total. My approach bears analogy to Campbell and Mankiw (1989), Lettau and Ludvigson (2004), and Hoffmann (2006). To build the bridge, one might interpret the balance-sheet identity as a budget constraint in present value form. Be it for regulatory reasons, be it for the purpose of profit maximization, the following chain of arguments draws on the idea that banks exhibit a constant *equity to balance-sheet total* ratio, the inverse of the *leverage* ratio.

To simplify, I split the balance-sheet total  $TBS_t$  only into equity  $EQUITY_t$  and external finance  $EFIN_t$  as a composite of other liability items<sup>3</sup> to arrive at the following version of the balance-sheet identity:

$$TBS_t = EQUITY_t + EFIN_t \quad (2)$$

Based on the assumption that banks exhibit a constant long-run *equity to balance-sheet total* ratio, it is possible to approximate these long-run ratios. For this purpose, I take a first-order Taylor expansion<sup>4</sup> of the balance-sheet identity around the *equity to total* ratio expressed in logarithms ( $equity_t - tbs_t$ ) and around the *external finance to total* ratio ( $efin_t - tbs_t$ ). Letting lower case letters denote logarithms, Equation (3) suggests an equilibrium long-run relationship between equity, external finance and the balance-sheet total  $tbs$ :

$$tbs_t = c + \gamma equity_t + (1 - \gamma) efin_t \quad (3)$$

$\gamma$  denotes the long-run equilibrium share of equity to balance-sheet total, whereas  $(1 - \gamma)$  gives the long-run share of external finance to the balance-sheet total. If banks exhibit constant equilibrium ratios, cointegration analysis serves as appropriate tool to examine Equation (4)

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<sup>3</sup>This approach ignores any regulatory restrictions, as no risk-weights are involved when referring to the balance-sheet total. For this reason, my paper restricts leveraging and deleveraging only to the balance-sheet total and the liability decomposition while abstracting from the structure of the asset side.

<sup>4</sup> A step-by-step log-linearization of the *equity* ratio is provided in the online appendix.



with  $\varepsilon_t$  as random deviation from the long-run ratios in period  $t$ :

$$tbs_t = c + \gamma equity_t + (1 - \gamma) efin_t + \varepsilon_t \quad (4)$$

Table 1 broadens the scope again. It lists the corresponding equations while splitting up debt into sub-components in line with the previously formed sets. By analogy,  $\delta_2^I$  denotes the long-run equilibrium share of bonds in the balance-sheet total, equivalently expressed as long-run *bond to balance-sheet total* ratio.

In short, if banks exhibit constant ratios, liability decomposition sets should be cointegrated. In what follows, I will reverse this argument. Cointegration analysis provides the tools to test whether banks do indeed exhibit constant ratios such as the *equity to total* ratio. Put differently, finding cointegration among liability set I to set IV would yield strong evidence that banks target constant *leverage* ratios, the flip side of the *equity to total*. However, in view of financial market turmoil and the subsequent banking crisis in September 2008, the question arises whether banks were actually able to target constant liability ratios.

As IMF (2011) puts forward, the key crisis events in 2007 and 2008 have left persistent traces in the liability decomposition of banks. Indeed, structural breaks in the cointegration term might stand for ruptures in long-run liability shares which invites me to interpret them as structural breaks in leverage or its decompositions.

In this vein, changes in *leverage* are not restricted to explicit movements in either *equity* or the balance-sheet total *tbs*. The definition of leverage by Equation (1) suggests that sudden changes in leverage might run through different channels represented by different liability reallocations. Set I to set IV reflect these channels. Applying cointegration tests in the presence of possible structural breaks sheds light on the channels that banks use to adjust their leverage. My empirical approach exploits balance-sheet data to examine how banks re-organize their liability decomposition to tune their leverage. Having found cointegrating relationships with structural breaks, I can apply the tools of cointegration analysis. Vector error correction models can shed light on how distinct balance-sheet items restore the equilibrium.

## 4 Empirical Evidence

### 4.1 Datasets and Sample Construction

Two datasets collected by the *Deutsche Bundesbank* set the stage for my empirical analysis. Both datasets consist of individual mandatory reports submitted by all banks with a German banking license. First, the “Monthly Balance-Sheet Statistics” (“Monatliche Bilanzstatistik”) dataset features comprehensive data on all balance-sheet items of German banks.<sup>5</sup> Second, the “External Position Report” (“Auslandsstatus”) as used by Buch et al. (2011b, 2013) offers the corresponding data by country of foreign business. After combining the External Position Report with the Monthly Balance-Sheet Statistics, I am able to use information on various classes of assets and liabilities and to distinguish securitized and non-securitized items by maturities. To study leverage in light of different liability decompositions, I construct time-series aggregates for the biggest commercial German banks. These universal banks conduct the whole array of banking businesses on global markets. For this reason, insights should be comparable to other globally operating universal banks possibly deemed “systemically relevant”.<sup>6</sup>

The dataset of my empirical analysis is constructed as follows. Starting from bank-level data, I restrict the sample to banks headquartered in Germany which, however, run foreign affiliates. My intention is to capture globally exposed banks with foreign commercial presence. In a second step I keep only those banks with a consecutive data record from January 2002 to April 2010 to avoid discrete jumps. In a third step, I aggregate the data to obtain time series of different kinds of liabilities and the balance-sheet total. The group of big commercial German banks has three members. Put differently, an observational unit could be characterized as a representative synthetic composite large commercial bank possibly deemed “systemically relevant”.

Table 2 presents some descriptive statistics. It relies on aggregated time-series data in levels and EUR billions. The underlying monthly sample ranges from January 2002 to April 2010.

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<sup>5</sup>The online appendix gives further details and exact definitions.

<sup>6</sup>For reasons of confidentiality, the Bundesbank does not allow to report results from individual time series estimations by bank.

Descriptive figures state that the domestic share in debt exceeds the foreign share (set II). Banks report almost five times more short-term than long-term debt (set III) while bank debt outstrips non-bank debt (set IV). Table 2 also gives descriptive statistics of the different risk variables which enter the short-run analysis as weakly exogenous variable.

## **4.2 Long-Run Equilibrium Ratios and Structural Breaks**

My paper examines leverage and the liability structure of balance sheets from a short and long-run perspective. This section focuses on the long-run. If banks target constant liability shares over time, liability decomposition sets as presented in Table 1 will be cointegrated. For this reason, cointegration analysis can test whether banks target constant ratios and whether they were able to do so during the crisis. Major changes in the funding conditions of banks, however, cast constant liability ratios into doubt. In econometric terms, I interpret major changes in these funding conditions as structural breaks. My analysis endogenously identifies structural breaks that ensue from key events during the period of financial market turmoil in 2007 and 2008.

### **4.2.1 The Sub-prime Mortgage Crisis 2007-2008**

This sketch of key crisis events borrows from the event logbook given by Brunnermeier (2009). A surge in sub-prime mortgage defaults marks the outset of financial markets worrying about the US mortgage market in February 2007. During May and June, several hedge funds of global banks like UBS or Bear Stearns experienced severe losses while rating agencies downgraded sub-prime securities. In July, short-term asset-backed commercial paper (ABCP) markets froze and a small German bank named IKB almost failed as it was unable to make up for the losses incurred by its conduit on the US ABCP market. Hence, the crisis started to spill over into Europe and other victims like the French bank BNP Paribas and the British Northern Rock followed suit in reporting problems. To prevent interbank markets from drying up, the European Central Bank and the US Federal Reserve started to inject liquidity and

launched other kinds of support measures in August 2007. A sequence of heavy write-downs alarmed financial markets in Fall 2007 and made them realize that total losses had been underestimated so far. In December 2007, the Federal Reserve introduced its Term Auction Facility (TAF) Program. Several European banks tapped TAF liquidity to relieve their US dollar funding pressure.<sup>7</sup> Soon, other financial intermediaries like insurance companies and government-chartered institutions like Fannie Mae and Freddie Mac stumbled in 2008. The first severely threatened US investment bank was Bear Stearns which had to be acquired by JPMorgan Chase to avoid its default in March 2007. In contrast, Lehman Brothers declared bankruptcy in September 2008 and thereby triggered a panic on global interbank markets. Under the shadow of the Lehman failure, the Federal Reserve decided to bail out AIG, a large international insurance company. In October 2008, the US stock market lost substantially while marking the spillover of trouble from the financial into the real sector.

#### **4.2.2 The Financial Crisis as a Break and Period of Uncertainty**

Cointegration absorbs the long-run patterns, whereas breaks reflect persistent changes. Indeed, my procedure splits the sample ranging from January 2002 to April 2010 into two sub-periods: one period before and one period after the endogenous break. Between 2002 and early signs of the crisis in 2007, my sample captures a period without major shocks on financial markets and a rather stable regulatory environment for large commercial banks. Then, I let the data speak to identify a break in the long-run ratios during the crisis which mark a rupture in long-run ratios. The post-break period is governed by uncertainty that ensues from the repercussion effects on financial markets, government interventions and previews on new sets of regulation. In other words, the crisis is not over during the post-break period. Government rescue measures are still unfolding. For instance, the Federal Reserve's TAF Program auctions its last loan in March 2010 which matures in April. This corresponds to the last date of my sample period. In this sense, my long-run analysis tells about the long-run patterns before the crisis and the endogenous breaks that mark the point in time at which banks fundamentally change these

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<sup>7</sup>see Buch et al. (2011a) on how German banks reacted to the TAF support measures.

patterns. The interaction coefficients reflect the channels that banks invoke to adjust to the period of uncertainty between the break and the end of the sample in April 2010.

### 4.2.3 Hypotheses about Structural Breaks

To form hypotheses about how key crisis events and thus changes in bank funding conditions impact liability ratios, I build on a workhorse banking model of Baltensperger and Milde (1987).<sup>8</sup> Baltensperger and Milde (1987) argue that banks simultaneously optimize the asset and liability structure of balance sheets to maximize profits in competitive markets. The trade-off between less profitable cash holdings and interest-bearing assets shapes the (i) *illiquidity risk*. By analogy, the tradeoff between deposit and equity finance shapes the (ii) *insolvency risk*. In this sense, banks form expectations about their liquidity needs and their aggregate return to manage these risks. To deal with both risks, banks have to bear objective costs. Indeed, illiquidity and insolvency risks ensue from how participants perceive and think about risks on financial markets.

I will interpret the endogenously estimated breaks which are specific to the liability set under consideration as a permanent shift in the parameters of the Baltensperger model. In this sense, one might think about the interbank market freeze as a surge in restructuring costs or a surge in the penalty rate on interbank markets. With respect to a bank's customers, key crises events might trigger a shift in the volatility of liquidity needs and/or a shock to the volatility of aggregate return. The respective optimal elasticities recommend a reduction of external finance. For this reason, I hypothesize that banks substitute equity for external finance once hit by the crisis. The Baltensperger model however remains silent about how exactly banks reallocate different kinds of debt within the category of external finance. My approach empirically discloses banks' reallocation patterns and will then link them to the key crisis events as described by Brunnermeier (2009).

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<sup>8</sup>The online appendix sketches their model and tailors it to my empirical setup. It further provides optimal elasticities as referred to in this section.

#### 4.2.4 Preliminary Tests and Preparation of the Long-Run Analysis

My analysis applies time-series techniques to each of the four liability decomposition sets. To test for constant liability ratios, I follow standard procedures to test for cointegration. I first run unit root tests on all individual time series and then proceed to run cointegration tests on all four liability decomposition sets. Ambivalent results on the cointegration tests point out that banks do not exhibit constant liability ratios over the entire sample period ranging from 2002 to 2010. Hence, finding no cointegration leads me to search for structural breaks in the cointegrating relationships. This long-run consideration finishes with dynamic ordinary least squares (DOLS) estimation of the long-run equilibrium ratios in the presence of structural breaks. I interpret structural breaks as evidence of liability reallocations induced by major ruptures in the funding conditions of banks.

**Unit Root Tests** To verify that all balance-sheet items in the liability sets of Table 1 have a unit root, I resort to the *DF-GLS test* of Elliot et al. (1996), the *KPSS test* (see Kwiatkowski et al., 1992) tests and the *Advanced Dickey-Fuller (ADF)* test (see MacKinnon, 2010). A time series that has a unit root in levels but exhibits stationarity in first differences is said to be *integrated of order one* denoted as  $I(1)$ . To give way to the cointegration analysis below, all variables in levels should be integrated of order one  $I(1)$ . Lütkepohl and Krätzig (2004) partly extend the definition of cointegration and allow for  $I(1)$  and  $I(0)$  variables to form a cointegrating relationship as long as a linear combination thereof is  $I(0)$ . Consequently, even if it turns out that some liability items do not fulfill the  $I(1)$  requirement, this should not harm the appropriateness of further cointegration and VECM analysis.

For each balance-sheet item I run the *DF-GLS test* on levels and first differences to find out whether time series of individual items are  $I(1)$ .<sup>9</sup> Only in case of foreign debt I cannot reject a unit root in first differences. For this reason, I apply the *KPSS test* as a second unit root test. This time, long-term debt and non-bank debt do not seem to be  $I(1)$ , whereas foreign debt immediately qualifies for cointegration analysis. As these two unit root tests point into

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<sup>9</sup>All details of the results are reported in the online appendix.

different directions for same rare cases, I apply the *Advanced Dickey-Fuller (ADF)* test as a third unit root test. In contrast to the previous results, the ADF test suggests that all balance-sheet items exhibit a unit root in levels but are stationary in first differences. For this reason, I proceed to test whether liability sets share a common trend as the three presented tests do not jointly disqualify any particular times series from cointegration analysis.

**Standard Cointegration Analysis** Cointegration analysis seeks to absorb long-run phenomena into a cointegration vector. Recall that if both long-run liability ratios and leverage are constant, liability sets should be cointegrated. Thus, cointegration analysis can test whether banks target constant liability ratios and whether they are able to achieve this aim when facing severe ruptures in their funding conditions. Table 3 features three different cointegration tests which are in turn applied to all sets for each banking group: the *Engle-Granger (EG)* test, Shin’s version of the *KPSS* test and *Johansen’s trace statistic*.

Engle and Granger (1987) suggest this residual-based test featuring a null hypothesis of non-cointegration, while critical values draw on MacKinnon (2010). The first panel of Table 3 suggests that the baseline set I and set IV which distinguishes bank and non-bank debt are cointegrated. However, the Engle-Granger test cannot reject the null hypothesis of non-cointegration in case of set II which involves a distinction between foreign and domestic debt and set III which splits debt into long-term and short-term debt. These mixed results invite to use a second cointegration test.

Shin (1994) develops a residual-based test with a null hypothesis of cointegration based on the previously discussed *KPSS* test. Shin’s *KPSS* test and the *Engle-Granger* test come to the same conclusion, if the Shin test cannot reject its null of cointegration and the *EG* test rejects its null of non-cointegration. As shown by the second panel of Table 3, this seems to be the case with respect to set II and III. Shin’s *KPSS* test rejects the null hypothesis of cointegration for both sets whereas it cannot reject cointegration as to set I and set IV.

Johansen (1995) relies on a likelihood ratio test with eigenvalues deriving from reduced regression techniques (see Lütkepohl and Krätzig, 2004). For each liability set, the Johansen test suggests one cointegrating relationship.

To conclude, three different cointegration tests come to different conclusions in case of set II and set III. However, these findings might suffer from a bias that ensues from unaccounted breaks in the cointegrating relationships. According to Haug et al. (2011), such a break might lead to a spurious unit root behavior among the cointegrating variables which ultimately renders the null hypothesis of no cointegration difficult to reject. Hence, my analysis turns to cointegration tests in the presence of structural breaks.

**Cointegration and Endogenous Structural Breaks** This paper centers on whether banks exhibit constant liability ratios. If major changes in the funding conditions constitute structural breaks in cointegrating relationships, I can interpret these breaks as channels of banks' leverage adjustment. Previous results from conventional cointegration analysis did not provide clear-cut evidence on possibly cointegrated sets of liability decompositions. Yet, intuition suggests that the balance-sheet total and liabilities as listed in the four sets of Table 1 share common stochastic trends. Structural breaks in the long-run relationships might solve the puzzle. Bai (1994, 1997), Kurozumi, 2002 and Carrion-i Silvestre and Sansó (2006) suggest an algorithm to search for endogenous breaks and subsequently test for cointegration in the presence of estimated breaks. Applied to my setup, their methodology serves several purposes. First, it yields explicit estimates of the long-run liability structure of banks. Second, endogenously estimated breaks indicate when a bank has changed the long-run liability pattern and interaction coefficients disclose how changes in leverage split up into distinct channels. Third, finding evidence of cointegration after accounting for structural breaks allows me to analyze short-run dynamics by means of vector error correction models (VECMs).

**Search and Test for Endogenous Structural Breaks** Gregory and Hansen (1996a,b) develop a cointegration test which allows for breaks in the intercept, the deterministic trend



and coefficient estimates. Their idea is to introduce the transition of a cointegrating equilibrium from one path to another. Yet, Gregory and Hansen do not account for the endogeneity of the regressors. Carrion-i Silvestre and Sansó (2006) tackle this issue and extend their model to a multivariate framework. Their suggested test statistic involves regression residuals from a first stage *DOLS* estimation in which all coefficients are interacted with a break dummy. Equation (5) projects their idea on the simplified liability decomposition. It expands Equation (4) by leads and lags of first differences, a structural break dummy  $B(\lambda)$  and the interaction terms.

$$\begin{aligned} tbs_t = & c + \gamma_0 equity_t + (1 - \gamma_0) efin_t + B(\lambda) + \gamma_1 equity_t * B(\lambda) + \gamma_2 efin_t * B(\lambda) \quad (5) \\ & + \sum_{k=-1}^1 \delta_k \Delta equity_{t+k} + \sum_{k=-1}^1 \tau_k \Delta efin_t + \varsigma_t \end{aligned}$$

where

$$B(\lambda) \begin{cases} 1 & \text{for } t > T_b \\ 0 & \text{otherwise} \end{cases} \quad \text{with } T_b = \lambda T$$

According to Bai (1994, 1997) and Kurozumi (2002), the break point can be estimated by minimizing the sequence of the sum of squared residuals over  $\lambda$ . Carrion-i Silvestre and Sansó (2006) prove that this procedure consistently estimates the break fraction parameter  $\lambda$ . As my interest lies in the long-term liability structure, the estimated breaks and subsequent reallocation patters, I resort to the following statistical procedures. To test the null hypothesis about long-term patters as described by cointegration in the presence of an estimated structural break, I follow Carrion-i Silvestre and Sansó (2006) while using the Lagrange Multiplier (LM-type) test statistic and their suggested critical values. To trace the reallocation patters, I apply t-tests for individual coefficients and Wald tests for the joint significance<sup>10</sup> of the break and interaction coefficients as proposed by Beckmann et al. (2011).

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<sup>10</sup>Indeed Murray, 2006 puts forward that Dynamic OLS estimation allows to apply standard t- and F-tests to the coefficient estimates.

The consistent estimate of  $\hat{\gamma}_0$  characterizes the long-run equilibrium *equity to total* ratio over the entire period. The coefficient estimate of the interaction term,  $\hat{\gamma}_1$  states to which extent the regime shift has modified the *equity to total* ratio. Hence, structural breaks in the cointegrating relationship can be interpreted as changes in the liability ratios. A further split of the liability components allows me to trace the channels of deleveraging more explicitly.

#### 4.2.5 Results on Long-Run Ratios and Structural Breaks

Table 4 present the results of baseline set I and set II which splits debt into *domestic* and *foreign debt* (set II). Table 5 differentiates *short-* and *long-term* debt (set III) as well as *bank* and *non-bank debt* (set IV). In both tables the first row gives the endogenously estimated break point which minimizes the sum of squared residuals (see Bai, 1994, 1997; Kurozumi, 2002; Carrion-i Silvestre and Sansó, 2006). Based on this estimated break point, DOLS results follow below. The respective interaction of liability items with the estimated break point carry the prefix “i\_” while the Wald test relies on the null hypothesis that the break dummy and all interaction terms are jointly equal to zero. To illustrate the breaks, Figure 1 exhibits the shares of debt decompositions in line with set II. The dotted vertical line marks the endogenously determined break.<sup>11</sup>

**Set I** According to the first column of Table 4, large commercial banks hold on average 10% as bonds and 76% of their liabilities as non-securitized debt. Equity amounts to an average of 5.3% and other liabilities make up about 9% of the total. The procedure by Bai (1994, 1997) and Kurozumi (2002) locates the break of the long-run ratios in April 2008.

Interaction effects of the break dummy with liability components tell about how banks reallocate their liabilities after April 2008. The first column of Table 4 suggest that banks significantly cut back on debt (-3.1%). This debt is characterized as non-securitized borrowing from banks and non-banks. Further analysis will disclose how changes in debt split

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<sup>11</sup>The online appendix shows analogous figures for the other debt decomposition sets.

up into distinct adjustment channels. Equity and bond issuance seem to be unaffected at this time, whereas the catch-all category of other liabilities picks up part of the restructuring (+0.09%). These stylized facts broadly align with the Baltensperger model and hint at a significant deleveraging of large commercial banks in April 2008. The Wald test hints at the overall significance of the break meaning that a significant reallocation has taken place in April 2008. To test for cointegration in the presence of the endogenously estimated break, I resort to the test developed by Carrion-i Silvestre and Sansó (2006). Its test statistic equals 0.0888 which denotes significance at the 5% but not at the 1%-level. In other words, I cannot reject cointegration given a structural break in April 2008 at the 1% level of significance.<sup>12</sup> One might attribute the lack of insignificance at the 5%-level to the fact that the period after April 2008 is rather short and includes a transition period of uncertainty in financial markets and regulation. However, the dominant break in April 2008 and the broad picture given by the DOLS analysis encourage further analysis in order to track the channels of banks' leverage adjustment within the debt category.

To put the break into historical perspective, a few weeks earlier, in mid March 2008, the investment bank Bear Stearns had run into severe financial difficulties and was ultimately acquired by JPMorgan Chase (see Brunnermeier, 2009 for the key events). Also in March 2008, the Fed had launched the *Term Securities Lending Facility*, and opened the discount window to investment banks under the *Primary Dealer Credit Facility* (PDCF). The Fed's aim was to reanimate the market for mortgage-related securities while trying to avoid stigmatization. Apparently, these incidences also induced, large global commercial banks to reallocate their liabilities.

**Set II** Set II splits debt into domestic versus foreign debt. Based on this liability decomposition, the procedure identifies a break already in June 2007. The different location of break

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<sup>12</sup>Critical values are computed from their simulations of model D with 4 explanatory variables and corresponding break fraction  $\lambda_{sel} = 0.75$ . Unfortunately, Carrion-i Silvestre and Sansó (2006) provide only critical values for the test with endogenously estimated break for up to 4 explanatory variables. As my short-run analysis relies on cointegrated sets, I will apply standard cointegration tests on the pre-break period for those sets that enter Section 4.3. The procedure to find endogenous breaks (see Bai, 1994, 1997; Kurozumi, 2002 and Carrion-i Silvestre and Sansó, 2006) works independently from the number of explanatory variables.

points explains why long-run averages might differ slightly from those previously presented. The second column in Table 4 shows that large commercial banks hold on average 37.3% domestic and 38.3% foreign debt. The long-run equity share amounts to 4.9%, whereas set I disclosed a long-run equity share of 5.3%. This hints at the fact that large commercial banks very smoothly raised equity between June 2007 and April 2008 as the interaction coefficients on equity denoting sudden ruptures in long-run shares turn out to be insignificant in both sets. The long-run shares of bonds and other liabilities remain almost unchanged.

Interaction coefficients tell about the channels of banks' leverage adjustment now distinguishing foreign and domestic debt. Banks substantially cut back on foreign debt (-6.9%) while raising bond funding (+1.2%) and domestic debt (+3.2%). Other liabilities slightly increase (+1.7%) as well. Two effects emerge, a "negative net debt effect" and a "substitution effect". Indeed, the Wald test states that the overall reallocation and thus both effects are significant. The "negative net effect" means that overall debt declines and banks slightly reduced their leverage in June 2007. This reaction aligns with the Baltensperger model. The "substitution effect" results from banks replacing foreign debt funding with bond and domestic debt funding. Foreign debt consists of non-securitized borrowing from banks and non-banks which captures the international inter- and intrabank market. My analysis hence finds that large commercial banks withdrew from international borrowing as early as June 2007.

To provide some historical context, Brunnermeier (2009) tells about a sequence of rating downgrades and severely troubled hedge funds between May and June 2007. He also mentions stressed credit markets which apparently also impinged on large commercial banks. Yet, the first bank, notably the German IKB being threatened by default was only rescued later in July 2007. It remains beyond the scope of my analysis to find out whether large commercial banks were literally unable to tap foreign funding or whether exploding foreign costs pushed them back to alternative domestic sources. To conclude, as early as June 2007 did large commercial banks slightly reduce their leverage and replace foreign debt by domestic and bond funding.

**Set III** Set III splits debt into short- and long-term debt. In line with the first column of Table 5, the search procedure locates the break in May 2008. Before, banks report a 9.5% bond, a 6.6% equity and an 8.8% other liability share on average. Short-term debt (65.1%) by far exceeds long-term debt (11.4%) according to these long-run ratios.

Interaction coefficients suggest again that several effects are at work. Banks significantly shrink their short-term debt (-6.9%) and expand their share of long-term debt (+4.3%). However, equity (-2.2%) and other liabilities (-0.9%) decline as well. The decline in equity might ensue from incurred losses and the decline in other liabilities from the debit balance on income and expenditure accounts. In terms of leverage, the overall reduction in debt and the drop in equity seem to work in opposite directions. More details on the components of equity and other liabilities might shed light on the underlying mechanisms. The Wald test finds that the reallocation pattern is highly significant.

According to the event logbook by Brunnermeier (2009), no particular crisis event takes place in May 2008. Yet Bear Stearn's emergency takeover in March 2008 still casts a shadow on financial markets which were still simmering under the surface. Several attempts by central banks were underway to ease pressure and support failing financial market participants. Large commercial banks bore traces of these developments as evidenced by write-downs and liability reallocations. In short, large commercial banks switch from short-term into long-term borrowing in May 2008 while effects on leverage are ambiguous.

**Set IV** Set IV splits debt into bank and non-bank debt. The second column of Table 5 presents the results based on an endogenously determined break<sup>13</sup> in April 2008. Set IV hints at the key role of interbank-funding. Bank debt constitutes a share of 42.3%, whereas non-bank debt only amounts to 34.1% of total liabilities. Indeed bank debt captures borrowing across all different maturities and does not distinguish between foreign or compatriot banks.

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<sup>13</sup>Actually the Bai (1994, 1997) and Kurozumi (2002) procedures yields two local minimums between January 2007 and January 2009. It locates the first one in April 2008 and the second in November 2008. I decide to focus on the first break for two reasons. First, if I used the second break, cointegration analysis on the pre-break period might suffer from a bias that ensues from the unaccounted first break in the cointegrating relationship. Second, my subsequent short-run analysis rests on the assumption that long-run ratios are stable which is only granted if I restrict the sample period to the first break.

Non-bank debt refers to liabilities *via-a-vis* households, the private non-bank and the public sector which also includes simple deposits. The long-run shares of bonds, equity and other liabilities are comparable in size to set I for which the procedure of Bai (1994, 1997), Kurozumi, 2002 and Carrion-i Silvestre and Sansó (2006) has identified the same break point. Again, the deleveraging broadly aligns with the Baltensperger model and the Wald test suggests that the restructuring is significant. To provide some historical background, the rescue of Bear Stearns in March 2008 and the Fed's subsequent emergency measures illustrate the stressed situation and uncertainty on financial markets. These circumstances urge interbank debt to contract. To sum up, large commercial banks significantly reduce their leverage in April 2008 with the deleveraging running through a reduction of interbank borrowing.

**Summary and Discussion** In sum, distinct crisis events during financial market turmoil in 2007 and 2008 have triggered major reallocations in the liability decomposition of large commercial banks. This long-run analysis has demonstrated that banks significantly reduced their leverage in June 2007 and April 2008. These significant adjustment mechanisms show that banks invoke different channels of leverage adjustment at different points in time. The precise description of banks' adjustment mechanisms and the timing of structural breaks might yield valuable insights for regulatory authorities and the future design of rescue measures.

To illustrate the usefulness of the cointegration approach, I link the split between long-run and short-run leverage considerations to the introduction of macro-prudential policy measures like the counter-cyclical capital buffer (CCB). The previous analysis considers endogenous long-run liability ratios which reflect profit maximizing choices of banks against a stable regulatory background. A change in the regulatory background like the activation of the CCB constitutes a structural break in long-run liability ratios. In contrast to the previous analysis however, banks would not be able to flexibly restructure their liability decomposition. Instead, the change in the long-run equity ratio would be pre-determined by the design of the CCB. To assess the consequences of an activated CCB on the short-term behavior of the bank, the regulator might draft different scenarios about how banks restructure their long term ratios.

Based on the observable long-run ratios, the design of the CCB and a certain scenario, the regulator might then apply the short run analysis to find out about how the CCB shapes the short-term behavior of the bank.

### 4.3 Short-Run Dynamics

The aim of this study is to analyze the adjustment patterns of bank liabilities from a short- and long-run perspective. Now, short-run responses to exogenous financial market developments take center stage. To build the bridge between bank liabilities, leverage and risks in financial markets, I again resort to a workhorse banking model of Baltensperger and Milde (1987). My analysis draws on four different risk measures to capture risks on various markets<sup>14</sup>: The *risk spread* captures risks on fixed income markets, *VIX* index sheds light on equity markets, the J.P. Morgan *FX-VXY* index refers to currency markets and the Credit Suisse First Boston's *CSFB Risk Appetite* index measures risk appetite across different markets. To reflect how risks shape the short-run balance-sheet dynamics, I apply vector error correction models (VECMs).

#### 4.3.1 Hypotheses on how the exogenous risk proxies shapes the liability decomposition

This section develops hypotheses about banks' optimal short-run reactions to changes in financial market risks. It borrows again from Baltensperger and Milde (1987)<sup>15</sup> with banks simultaneously optimizing assets and liabilities to maximize profits in competitive markets. Two tradeoffs exist which shape the *illiquidity risk* and the *insolvency risk*. Again, banks form expectations and incur costs to manage these risks while both are rooted in the banks' perceptions and interpretations of financial market developments. My short-run analysis uses four different measures of developments on core markets of bank activity to examine the reactions of banks.

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<sup>14</sup>I am grateful to an anonymous referee to point at different risk measures representing different markets of bank activity.

<sup>15</sup>Again, the online appendix presents more details on the model.

To proxy risks on fixed income markets<sup>16</sup>, I use the *risk spread*, defined as return difference between “Moody’s Baa-” and “AAA”-rated long-run corporate bonds. Gatev and Strahan (2006) use the risk spread to reflect default risks. To proxy risks on equity markets, I resort to the *VIX* index. The Chicago Board of Options Exchange computes this implied volatility index from a number of put and call options on the S&P 500 index (see Becker et al. 2009). Ang et al. (2009) link *VIX* innovations to the cross section of equity returns as the *VIX* reflects equity market volatility and its price (see Adrian and Shin, 2010).

To proxy risks on currency markets, I borrow from Mancini et al. (2013) while using the J.P. Morgan *FX-VXY* index. This index captures aggregate volatility in currencies through a turnover-weighted index of G7 currencies. As opposed to the risk spread and the *VIX* index, the *FX-VXY* index expands the geographical coverage of risk proxies. Finally, I use a composite *Risk Appetite* index created by Credit Swiss First Boston (CSFB) which tracks 64 individual indices of bonds and equities in developed and emerging markets. The *CSFB Risk Appetite* index draws on the estimated slope coefficient from a cross-sectional linear regression of risk on excess returns (see Wilmot, 2004). In sum, these four measures incorporate different markets of bank activity in terms of asset classes and geographical coverage.

To translate Baltensperger and Milde (1987)’s optimal adjustments into leverage dynamics, I recall that Equation (1) defines leverage as the ratio of balance-sheet total and equity. According to optimality conditions, an exogenous increase in financial market risks triggers a balance-sheet contraction and a simultaneous rise in equity which ultimately results in a lower leverage ratio. As equity is usually rather persistent, I expect that banks prefer to cut debt. Some short-run changes in equity might however result from incurred losses. My empirical analysis of the short run focuses on liability set IV which distinguishes bank and non-bank debt. Hence, this short-run analysis allows me to track the channels of short-term leverage adjustments with a distinction between bank and non-bank debt.

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<sup>16</sup>Risk proxies like the TED- or OIS-Spread cannot enter my analysis. These proxies relate to the interbank market and this might cast doubt on their weak exogeneity in the first place.



### 4.3.2 Econometric Tools

Section 3.2 has pointed out that cointegration hinges on the assumption that liabilities exhibit constant long-run equilibrium ratios. However, with banks facing financial market turmoil and key ruptures in their funding conditions, Section 4.3 has shown that cointegration might only exist after taking structural breaks into account. Between 2002 and early signs of the crisis in 2007, my sample reflects a period without major financial or regulatory shocks. To provide a proper view on the short-run adjustment mechanisms given that long-run relationships are rather stable, this section limits its view on the liability decomposition of set IV before the endogenously estimated break in April 2008. This procedure allows me to study how the risk variables shape the short-run liability adjustments.

Based on *Granger's representation theorem* (see Engle and Granger, 1987), Equation (6) gives a VECM which captures the joint dynamics of liabilities and the balance-sheet total:

$$\Delta \mathbf{x}_t = \alpha \beta' \mathbf{x}_{t-1} + \Pi \Delta \mathbf{x}_{t-1} + \varepsilon_t \quad (6)$$

In line with the stylized version previously presented, the balance-sheet total  $tbs_t$  as well as all individual liability items ( $equity_t$  and  $efin_t$ ) enter the vector  $\mathbf{x}_t$  as endogenous variables. Following Lütkepohl and Krätzig (2004), a risk variable enters Equation (6) as weakly exogenous<sup>17</sup> variable to model its potential persistence. Thus,  $\mathbf{x}_t$  denotes a  $(K + 1) \times 1$  vector with  $K - 1$  liability items  $(1, \dots, k, \dots, K - 1)$ , the balance-sheet total  $tbs$  and the respective risk variable.  $\varepsilon_t$  denotes the  $(K + 1) \times 1$  vector of disturbances. In case of  $r$  cointegrating relationships,  $\alpha$  and  $\beta$  are parameter matrices of dimension  $(K + 1) \times r$ , whereas  $\Pi$  is a  $(K + 1) \times (K + 1)$  matrix of parameters to estimate.

As captured by  $\beta' \mathbf{x}_{t-1}$ , I impose two cointegrating relationships on Equation (6), first the risk variable in isolation and second the balance-sheet identity. The first cointegration term

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<sup>17</sup>Section 4.3 will first provide a test of weak exogeneity based on the cointegrating vector derived in Section 3. Risk variables that turn out to be weakly exogenous in the pre-test will then qualify for the VECM analysis. Moreover, estimation results of the VECM on individual coefficients will provide a second test for weak exogeneity.

models the risk variable as weakly exogenous, persistent variable while muting all balance-sheet variables. The second cointegrating term picks up the long-run equilibrium relationship of set IV while muting the respective risk variable. My intention to study the short-run dynamics before structural breaks materialize justifies the reduced sample estimation.

In the presence of two cointegrating relationships ( $r = 2$ ), matrix  $\alpha$  can be decomposed into two vectors of size  $(K+1)$  with the  $\alpha_{\bullet,1}$  relating to the risk variable and  $\alpha_{\bullet,2}$  relating to the balance-sheet identity. Parameter element  $\alpha_{1,1}$  captures the persistence of the risk variable, whereas elements  $\alpha_{2,1}$  to  $\alpha_{K+1,1}$  inform about the sensitivity of endogenous variables towards lagged values of the risk proxy. Significant estimates of elements  $\alpha_{2,2}$  to  $\alpha_{K+1,2}$  indicate whether these endogenous variables contribute to restore the long-run equilibrium ratios. Further, the size of  $\alpha_{2,2}$  to  $\alpha_{K+1,2}$  tells about the speed of adjustment. To test for weak exogeneity of the risk variables with respect to the balance-sheet identity I run simple t-tests on  $\hat{\alpha}_{1,2}$ . Besides, parameter matrix  $\Pi$  tells about the impact of lagged changes in the risk and balance-sheet variables.

### 4.3.3 Results on Short-Run Adjustments

**Pre-Tests for the Short-Run Analysis** Two tests precede the VECM analysis of liability set IV which splits debt into bank and non-bank debt. The first test tells about whether set IV is cointegrated during the pre-break period. The second test reveals which of the risk variables are weakly exogenous with respect to the cointegrating relationship. Given the endogenously estimated break in April 2008, the KPSS test on the pre-break period rejects cointegration at the 5%-level of significance but it cannot reject cointegration at the 1%-level of significance<sup>18</sup>. The Johansen procedure strongly supports one cointegrating relationship, whereas the Engle-Granger test tends to find no cointegrating relationship. Overall, I conclude that there is weak empirical evidence in favor of set IV being cointegrated before April 2008 with the balance-sheet identity strongly supporting cointegration from a theoretical point of

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<sup>18</sup>The KPSS test statistic amounts to 0.1053 while Shin, 1994 provides the following critical values in case of 5 regressors: 0.097 (5%-level); 0.12 (2.5%-level); 0.158 (1%-level).

view.

To test which exogenous risk variables qualify for the VECM by being weakly exogenous with respect to the cointegrated balance-sheet identity of set IV, I follow Beckmann et al. (2011). I regress risk variables in first differences on the one period lagged residual of the cointegration term as described by Equation (7).

$$\Delta riskvariable_t^i = c^i + \lambda^i cointresid_{t-1} + \varsigma_t^i \quad (7)$$

As the sample ranges only until March 2008 to exclude the break point, simple t-tests on  $\hat{\lambda}^i$  inform about weak exogeneity. Table 6 shows that only the *risk spread* is not weakly exogenous with respect to the cointegrating residuals. In case of the *VIX*, the *CSFB Risk Appetite* and the *FX-VXY* index, I cannot reject that  $\lambda$  equals zero which means that these risk variables qualify as being weakly exogenous.

**VECM Analysis with Weakly Exogenous Variables** This section presents results on the short-run analysis. It draws on the cointegrated balance-sheet identity of set IV before the estimated break in April 2008 and features the *VIX*, the *CSFB Risk Appetite* and the *FX-VXY* index as weakly exogenous risk variables. To optimally specify the lag length I follow Lütkepohl and Krätzig (2004) who show that Hannan and Quinn’s info criterion (HQIC) and the Schwarz’s Bayesian information criterion (SBIC) yield consistent estimates of the true lag length. Both criteria suggest using one lag which guides me to drop the  $\Pi\Delta\mathbf{x}_{t-1}$  term of lagged first differences from the model in Equation (6).

Each column in Table 7 to Table 9 stands for a variable<sup>19</sup> entering the VECM in first differences. In each table, the first column refers to the respective risk variable and subsequent columns feature the balance-sheet identity variables as described by liability set IV. The respective risk variable enters the VECM as weakly exogenous variable and one lag accounts for its potential persistence. The cointegration term based on the balance-sheet identity of liability set IV is denoted as *coint\_identity*. A t-test on the the estimated coefficient  $\hat{\alpha}_{1,2}$  on *coint\_identity*

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<sup>19</sup>D denotes first differences and L denotes lags.

serves as a second test for weak exogeneity. Estimated coefficients  $\hat{\alpha}_{2,1} \dots \hat{\alpha}_{K+1,1}$  on the risk variable inform about which endogenous balance-sheet variables respond to a change in financial market risks. Estimated coefficients  $\hat{\alpha}_{2,2}$  to  $\hat{\alpha}_{K+1,2}$  on *coint\_identity* in the balance-sheet equations indicate which balance-sheet items correct for past deviations from the long-run equilibrium. Besides, two statistics reflect the fit of the model: First, the  $R^2$  statistic gives the share of explained variation in each involved variable. Second, the p-value of a *Chi-square* test indicates whether all estimated coefficients in a particular endogenous equation jointly equal zero.

**The VIX index as a proxy of Equity Markets** The results of Table 7 confirm the weak exogeneity of the *VIX* index with respect to the balance-sheet identity of liability set IV. According to the first row, the *VIX* index is persistent. It has a significantly positive impact on the balance-sheet total (*tbs*), on bonds and on bank debt, whereas the impact on other liabilities is negative but small. In terms of leverage, the relative size of the estimates reveals that more risks on equity markets encourage banks to increase their leverage which contrasts with the optimal predictions of the Baltensperger model. This effect mainly runs through a higher level of bank and bond finance. As to the error correction mechanism (*coint\_identity*), it turns out that all balance-sheet items except for non-bank debt contribute to restore the long-run equilibrium ratio. The fact that *non-bank* debt contains mainly deposits might explain this outcome. Table 7 points out that the model with the *VIX* index as *weakly exogenous* variable explains substantial shares in, for instance, *tbs* (23.4%) or *debt\_bank* (23.1%). According to the p-value of the Chi-squared test<sup>20</sup>, coefficients are jointly significant at the 5% level in the *tbs*, the *bond*, *debt\_bank* and *lother* equation. To conclude, a rise in the *VIX* index encourages banks to increase their leverage basically by expanding their bank and bond finance.

**The CSFB Risk Appetite Index as Aggregate Risk Proxy** In line with Table 8, the CSFB risk appetite index turns out to be weakly exogenous and persistent. To shed light on how large commercial banks respond to an increase in this index, the first row tells that banks

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<sup>20</sup>Denoted as Pval(Chi\_squared).

shrink their balance sheet and cut back on bank-debt. These effects hint at a decline in bank leverage once the *CSFB Risk Appetite* Index increases which aligns with the Baltensperger model. The second row of results shows that only the balance-sheet total, bank debt and equity contribute to the error correction mechanism. In parallel to the previous results, this model with the *CSFB Risk Appetite* Index as weakly exogenous risk proxy explains substantial shares in the variation of *tbs* (26.6%) and *debt\_bank* (25.5%). The Chi-squared test finds that coefficients are jointly significant in the balance-sheet total, the bank debt and the equity equation. In sum, banks reduce their leverage given a raise in the *CSFB Risk Appetite* Index again running through the balance-sheet total and bank debt.

**The VX-FXY Index as Proxy of Risk on Currency Markets** Table 9 again supports weak exogeneity and persistence of the *FX-VXY* index which captures risks on currency markets. The reaction of bank variables seems to be weaker than in case of previous risk measures. In response to higher risks on currency markets, bank debt increases while other liabilities drop. Both effects are of similar size which hints at a substitution effect. The impact on leverage is ambiguous. With respect to the error correction mechanism, all balance-sheet variables except for bond finance and other liabilities restore the long-run equilibrium. High shares of variation are explained in *tbs* (23.1%), the *debt\_bank* (18.5%) and – to some extent – the equity equation (14%). Again, the Chi-squared tests confirms this pattern. In short, risks on currency markets seem to exercise a weaker impact on banks with leverage remaining almost unchanged.

**Summary and Discussion** Distinct risk proxies on different kinds of financial markets exercise different impacts on bank leverage. More risks on equity markets induce large commercial banks to increase their leverage, whereas more risk appetite in general induces banks to reduce their leverage. Risks on currency markets seem to play a minor role. One strong finding of my short-run analysis is that the balance-sheet total and bank debt exhibit the strongest reactions to changes in financial market risks. To correct for short-run deviations from the long-term ratios, almost all components of liability set IV seem to take part in the

adjustment mechanisms.

These findings yield valuable information for how regulators should think about the short-run reaction of banks to developments on financial markets. First, banks seem to distinguish between different types of risks on different financial markets and shape their response accordingly. My analysis draws on a synthetic large commercial German bank with global operations and a comprehensive business model that exposes this bank to all kinds of shocks. As many banks on the international stage share these characteristics, the advantage of this approach is that insights easily transfer to large, possibly deemed “systemically relevant”, commercial banks from other countries. The disadvantage lies in the lack of idiosyncratic bank features and country-specific regulation. However, several recent developments suggest that the rules imposed on global banks become more and more similar. First, regulation becomes more and more harmonized under the auspices of *Basel III*. Second, in case of banks serving international customers, national regulation spills over into the foreign markets as illustrated by the US *Foreign Account Tax Compliance Act* (FATCA). Third, in an attempt to reduce regulatory arbitrage and establish common standards, supra-national authorities like the ECB will soon be responsible for large commercial banks headquartered in different countries.

## 5 Discussion and Conclusion

This study separates the long-run from the short-run dimension in the analysis of bank leverage and related liability ratios. If banks exhibit constant liability ratios, sets of liabilities form cointegrating relationships. Hence, cointegration analysis absorbs the long-run patterns and can test whether banks target certain liability ratios. My analysis shows that liability sets are only cointegrated when taking structural breaks into account. I endogenously identify the structural breaks during the financial crisis in 2007 and 2008 that triggered major reallocation in four different liability decomposition sets of large commercial German banks. Thus, for the long run, this procedure allows me to trace the channels that banks invoke to adjust their long-run liability structure when facing key ruptures in their funding conditions. For the short

run, my results point at those liabilities that adjust for past deviations from the long-run ratios as induced by changes in risks on distinct markets of bank activity.

Findings on the long run suggest large commercial banks significantly cut their leverage in June 2007 and April 2008. As early as June 2007 did large commercial banks withdraw from foreign borrowing while substituting domestic debt and bond funding for foreign debt. In April 2008, the deleveraging ensues from a contraction of interbank borrowing.

Findings on the short-run point out that banks' reactions to risk dynamics vary considerably across the type of financial market. Higher risks on equity markets seem to induce banks to increase their leverage, whereas more risks on currency markets apparently play a minor role. More risk appetite in general seems to discourage banks from jumping on the bandwagon. Across all different risk proxies, interbank debt turns out to perform a key valve function.

To conclude, a proper analysis of banks' liability structures requires to distinguish a short- and a long-run dimension.

These results yield valuable insights for policymakers and regulatory authorities. From a long-run point of view, a profound understanding of banks' funding structure, the adjustment patterns to structural breaks and the endogenous timing of major reallocations yield valuable insights to assess current policy or rescue measures, to design future regulation and to advance the effectiveness of monetary policy.

Further, while interpreting macro-prudential policy measures like the counter-cyclical capital buffer as structural breaks of long-run liability ratios, the regulator might use cointegration analysis and VECMs to assess the implications on the short-run behavior. From a short-run point of view, my results might serve as an ingredient to form expectations about short-run reactions of banks to developments on different financial markets. As many global, possibly systemically relevant banks share the characteristics and business models of large commercial German banks, these findings should be of interest to an international audience of regulators and policy makers who try to establish common standards for banks in the wake of recent financial crisis.

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Table 1: Liability Decompositions

<i>Set</i>	<i>Liability Decomposition</i>
I	$TBS_t = \delta_1^I DEBT_t + \delta_2^I BOND_t + \delta_3^I EQUITY_t + \delta_4^I LOTHER_t$
II	$TBS_t = \delta_1^{II} DEBT\_DOM_t + \delta_2^{II} DEBT\_FOR_t + \delta_3^{II} BOND_t + \delta_4^{II} EQUITY_t + \delta_5^{II} LOTHER_t$
III	$TBS_t = \delta_1^{III} DEBT\_SHORT_t + \delta_2^{III} DEBT\_LONG_t + \delta_3^{III} BOND_t + \delta_4^{III} EQUITY_t + \delta_5^{III} LOTHER_t$
IV	$TBS_t = \delta_1^{IV} DEBT\_BANK_t + \delta_2^{IV} DEBT\_NONB_t + \delta_3^{IV} BOND_t + \delta_4^{IV} EQUITY_t + \delta_5^{IV} LOTHER_t$

Notes:  $DEBT_t$  non-securitized external debt,  $BOND_t$  securitized external debt,  $EQUITY_t$  equity,  $LOTHER_t$  residual liability category,  $EQUITY_t$  equity and residual liability category,  $DEBT\_DOM_t$  domestic debt,  $DEBT\_FOR_t$  foreign debt,  $DEBT\_SHORT_t$  short-term debt,  $DEBT\_LONG_t$  long-term debt,  $DEBT\_BANK_t$  debt via-a-vis banks,  $DEBT\_NONB_t$  debt vis-a-vis non-banks.

Figure 1: Shares and Breaks: Domestic vs. Foreign Debt (Set II)

Notes: This graph displays the share of domestic debt in blue and foreign debt in red. The dashed line indicates the identified break in June 2007.

Table 2: Descriptive Statistics

	<i>Obs</i>	<i>Mean</i>	<i>Std. Dev.</i>	<i>Min</i>	<i>Max</i>
<b><i>Bank balance-sheet Variables</i></b>					
tbs	400	728.74	135.83	581.08	1074.07
debt	100	546.53	96.15	422.93	810.40
bond	100	77.12	20.12	54.53	117.96
debt_dom	100	289.41	67.85	199.58	448.46
debt_for	100	257.11	32.42	206.85	376.53
equity	100	33.71	7.18	26.92	53.96
lother	100	71.39	17.72	49.67	127.79
debt_short	100	453.92	70.05	345.97	646.10
debt_long	100	92.61	31.17	64.37	165.79
debt_bank	100	297.76	50.86	218.27	405.31
debt_nonb	100	248.77	49.01	194.12	409.99
<b><i>Weakly Exogenous Risk Variables</i></b>					
spread_risk	100	1.19	0.57	0.62	3.38
VIX	100	21.25	9.74	10.42	59.89
FX-VXY	100	10.28	3.03	5.95	23.03
CSFB Risk Appetite	100	18.03	3.11	12.25	25.58

Notes: Mean, standard deviation, minimum and maximum of bank balance-sheet variables are expressed in EUR bn. The risk spread (spread\_risk) is given in percent while other weakly exogenous risk variables are displayed as indices. Variables are described in the Data Appendix.

Table 3: Simple Cointegration Tests

	Set I	Set II	Set III	Set IV
<b><i>Engle-Granger Test</i></b>				
test statistic	-5.147**	-4.452	-4.213	-6.053***
$H_0$ : Non-cointegration				
<b><i>Shin's KPSS Test</i></b>				
test statistic	0.071	0.089*	0.122**	0.073
$H_0$ : Cointegration				
<b><i>Johansen's Trace Statistic (number of cointegrating relationships)</i></b>				
number	1	1	1	1

Notes: Significance indicated by \* =10% level, \*\*=5% level, \*\*\*=1% level. Balance-sheet variables enter the analysis in terms of natural logarithms. **Engle-Granger Test:** Critical values are based on MacKinnon (2010): set I: crit(1%)=-4.83; crit(5%)=-4.211; crit(10%)=-3.895; set II to set IV:crit(1%)=-5.183; crit(5%)=-4.558; crit(10%)=-4.24; **Shin's KPSS Test:** Critical values are based on Shin (1994): set I: crit(1%)=0.208; crit(5%)=0.121; crit(10%)=0.094; set II to set IV: crit(1%)=0.158; crit(5%)=0.097; crit(10%)=0.075. Test statistics rely on automatic bandwidth selection and a quadratic kernel as suggested by Hobijn et al. (2004).

Table 4: DOLS: Liability Set I and Set II

<b>Set I</b>		<b>Set II</b>	
<i>endogenous break date</i>	<i>2008m4</i>	<i>endogenous break date</i>	<i>2007m6</i>
bond	0.100*** (0.003)	bond	0.100*** (0.004)
debt	0.760*** (0.005)	debt_dom	0.373*** (0.005)
		debt_for	0.383*** (0.004)
equity	0.053*** (0.005)	equity	0.049*** (0.007)
lother	0.091*** (0.002)	lother	0.092*** (0.003)
i_bond	0.000 (0.008)	i_bond	0.012** (0.006)
i_debt	-0.031*** (0.007)	i_debt_dom	0.032*** (0.009)
		i_debt_for	-0.069*** (0.008)
i_equity	-0.001 (0.005)	i_equity	0.004 (0.008)
i_lother	0.009** (0.003)	i_lother	0.017*** (0.006)
break	0.481** (0.190)	break	0.117 (0.183)
Constant	0.731*** (0.107)	Constant	1.426*** (0.122)
Observations	97	Observations	97
Wald test	33.91	Wald test	607.0
Pval(Wald,5)	0	Pval(Wald, 6)	0

Notes: The first row gives the endogenously estimated break point at which the sum of squared residuals over the break fraction  $\lambda$  attains its minimum (see Bai, 1994 and 1997; Kurozumi, 2002). Based on this estimated break point, DOLS results follow with break interaction terms coded as  $i^*$ . Leads and lags of first differences are included but not reported but. The Wald test relies on the null hypothesis that the break dummy and interaction terms are jointly equal to zero. Balance-sheet variables enter the analysis in terms of natural logarithms. HAC standard errors are reported in parenthesis. Significance indicated by \* =10% level, \*\*=5% level, \*\*\*=1% level.

Table 5: DOLS: Liability Set III and Set IV

<b>Set III</b>		<b>Set IV</b>	
<i>endogenous break date</i>	<i>2008m5</i>	<i>endogenous break date</i>	<i>2008m4</i>
bond	0.095*** (0.004)	bond	0.101*** (0.003)
debt_short	0.651*** (0.007)	debt_bank	0.423*** (0.005)
debt_long	0.114*** (0.003)	debt_nonb	0.341*** (0.005)
equity	0.066*** (0.008)	equity	0.053*** (0.005)
lother	0.088*** (0.004)	lother	0.088*** (0.004)
i_bond	-0.018 (0.012)	i_bond	-0.007 (0.013)
i_debt_short	-0.069*** (0.008)	i_debt_bank	-0.022*** (0.006)
i_debt_long	0.043*** (0.009)	i_debt_nonb	0.010 (0.009)
i_equity	-0.022** (0.011)	i_equity	-0.005 (0.005)
i_lother	-0.009** (0.004)	i_lother	0.008*** (0.002)
break	1.502*** (0.319)	break	0.327 (0.237)
Constant	0.875*** (0.142)	Constant	1.242*** (0.109)
Observations	97	Observations	97
Wald test	272.5	Wald test	76.47
Pval(Wald,6)	0	Pval(Wald,6)	0

Notes: The first row gives the endogenously estimated break point at which the sum of squared residuals over the break fraction  $\lambda$  attains its minimum (see Bai, 1994 and 1997; Kurozumi, 2002). Based on this estimated break point, DOLS results follow with break interaction terms coded as  $i^*$ . Leads and lags of first differences are included but not reported but. The Wald test relies on the null hypothesis that the break dummy and interaction terms are jointly equal to zero. Balance-sheet variables enter the analysis in terms of natural logarithms. HAC standard errors are reported in parenthesis. Significance indicated by \* =10% level, \*\*=5% level, \*\*\*=1% level.



Table 6: Test for Weak Exogeneity of Risk Variables

	<i>D.spread_risk</i>	<i>D.risk_vix</i>	<i>D.risk_csfb</i>	<i>D.risk_vxy</i>
L.coint_identity	11.743* (6.216)	5.038 (15.238)	-2.610 (9.208)	-4.016 (7.703)
Constant	-0.002 (0.008)	0.001 (0.018)	-0.000 (0.011)	0.005 (0.009)
Observations	74	74	74	74
$R^2$	0.047	0.002	0.001	0.004

Notes: This table tests for weak exogeneity of the risk variables with respect to the cointegrating relationship described by set IV. As suggested by Beckmann et al. (2011), I regress the risk variables in first difference on lagged residuals of the cointegrating relationship during the pre-break period. The t-test on the estimated coefficient of *coint\_identity* tells whether the risk variable adjusts to lagged values of the error term of the balance-sheet identity cointegrating relationship during the pre-break period. In other words, the t-test reveals whether the risk variable is weakly exogenous.  $R^2$  gives the share of variance explained by included variables in the respective equation. Balance-sheet variables and risk variables except for the risk spread enter the analysis in terms of natural logarithms. Significance is indicated by \* =10% level, \*\*=5% level, \*\*\*=1% level.

Table 7: VECM Liability Set IV: **VIX** Index as Risk Variable

	<i>D.risk_vix</i>	<i>D.tbs</i>	<i>D.bond</i>	<i>D.debt_bank</i>	<i>D.debt_nonb</i>	<i>D.equity</i>	<i>D.lother</i>
L.risk_vix	-0.18** (0.086)	0.04*** (0.011)	0.05** (0.022)	0.09*** (0.024)	-0.011 (0.014)	0.008 (0.010)	-0.05** (0.018)
L.coint_identity	5.829 (5.497)	-3.05*** (0.722)	-4.06*** (1.437)	-6.81*** (1.529)	0.50 (0.874)	-1.28* (0.672)	1.98* (1.165)
Constant	-0.001 (0.019)	0.002 (0.002)	0.001 (0.005)	-0.000 (0.005)	0.003 (0.003)	-0.002 (0.002)	0.005 (0.004)
Observations	74	74	74	74	74	74	74
$R^2$	0.064	0.234	0.113	0.231	0.028	0.064	0.104
Pval(Chi_squared)	0.182	0.001	0.029	0.001	0.559	0.181	0.042

Notes: This table shows the result of a VECM estimation. *D.* denotes first differences and *L.* denotes one lag. Results rely on the reduced sample prior to the estimated break in April 2008. *L.risk\_vix* represents lagged values of the VIX index. *L.coint\_identity* refers to the balance-sheet identity of set IV modeled as cointegration term. A t-test of coefficient estimate on *L.coint\_identity* in the risk variable equation provides a second test for weak exogeneity. *Pval(Chi\_squared)* gives the p-value of the test of joint significance of all included variables in the respective equation;  $R^2$  gives the share of variance explained by included variables in the respective equation. Balance-sheet variables and risk variables enter the analysis in terms of natural logarithms. Standard errors are reported in parenthesis and significance is indicated by \* =10% level, \*\*=5% level, \*\*\*=1% level.

Table 8: VECM Liability Set IV: *CSFB Risk Appetite* Index as Risk Variable

	<i>D.risk_csfb</i>	<i>D.tbs</i>	<i>D.bond</i>	<i>D.debt_bank</i>	<i>D.debt_nonb</i>	<i>D.equity</i>	<i>D.lother</i>
L.risk_csfb	-0.15** (0.068)	-0.03** (0.015)	0.013 (0.031)	-0.09*** (0.031)	0.012 (0.018)	-0.000 (0.014)	0.024 (0.025)
L.coint_identity	-1.33 (3.236)	-3.21*** (0.691)	-1.49 (1.464)	-6.82*** (1.472)	-0.18 (0.854)	-1.58** (0.647)	0.095 (1.180)
Constant	0.001 (0.011)	0.001 (0.002)	0.002 (0.005)	-0.001 (0.005)	0.003 (0.003)	-0.002 (0.002)	0.005 (0.004)
Observations	74	74	74	74	74	74	74
$R^2$	0.071	0.266	0.038	0.255	0.030	0.092	0.040
Pval(Chi_squared)	0.142	0.001	0.429	0.001	0.536	0.066	0.411

Notes: This table shows the result of a VECM estimation. *D.* denotes first differences and *L.* denotes one lag. Results rely on the reduced sample prior to the estimated break in April 2008. *L.risk\_csfb* represents lagged values of the *CSFB Risk Appetite* index. *L.coint\_identity* refers to the balance-sheet identity of set IV modeled as cointegration term. A t-test of coefficient estimate on *L.coint\_identity* in the risk variable equation provides a second test for weak exogeneity. *Pval(Chi\_squared)* gives the p-value of the test of joint significance of all included variables in the respective equation;  $R^2$  gives the share of variance explained by included variables in the respective equation. Balance-sheet variables and risk variables enter the analysis in terms of natural logarithms. Standard errors are reported in parenthesis and significance is indicated by \*=10% level, \*\*=5% level, \*\*\*=1% level.

Table 9: VECM Liability Set IV: FX-VXY Index as Risk Variable

	<i>D.risk_vxy</i>	<i>D.tbs</i>	<i>D.bond</i>	<i>D.debt_bank</i>	<i>D.debt_nonb</i>	<i>D.equity</i>	<i>D.lother</i>
L.risk_vxy	-0.13* (0.067)	0.020 (0.017)	-0.040 (0.036)	0.07* (0.038)	0.007 (0.021)	-0.010 (0.015)	-0.06** (0.028)
L.coint_identity	0.596 (0.678)	-0.72*** (0.175)	0.071 (0.364)	-1.46*** (0.381)	-0.39* (0.207)	-0.44*** (0.156)	0.402 (0.284)
Constant	-0.001 (0.010)	0.001 (0.003)	0.002 (0.006)	0.001 (0.006)	0.001 (0.003)	-0.003 (0.002)	0.004 (0.004)
Observations	74	74	74	74	74	74	74
$R^2$	0.053	0.231	0.029	0.185	0.071	0.142	0.090
Pval(Chi_squared)	0.263	0.001	0.549	0.001	0.144	0.008	0.070

Notes: This table shows the result of a VECM estimation. *D.* denotes first differences and *L.* denotes one lag. Results rely on the reduced sample prior to the estimated break in April 2008. *L.risk\_vxy* represents lagged values of the *FX-VXY* index. *L.coint\_identity* refers to the balance-sheet identity of set IV modeled as cointegration term. A t-test of coefficient estimate on *L.coint\_identity* in the risk variable equation provides a second test for weak exogeneity. *Pval(Chi\_squared)* gives the p-value of the test of joint significance of all included variables in the respective equation;  $R^2$  gives the share of variance explained by included variables in the respective equation. Balance-sheet variables and risk variables enter the analysis in terms of natural logarithms. Standard errors are reported in parenthesis and significance is indicated by \*=10% level, \*\*=5% level, \*\*\*=1% level.